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Rotations with Broccoli for Soilborne Disease Management in Conventional and Organic Strawberry Production Systems

TABLE OF CONTENTS

ABSTRACT

Wilt caused by *Verticillium dahliae* is a major disease in organic and in non-fumigated conventional strawberry production systems in California. The influence of rotations and residue incorporation on wilt, growth and yield of strawberry was studied in the two systems. In both systems, two successive crops of broccoli or lettuce, and residue incorporation were followed by strawberry. After rotation, the numbers of microsclerotia (MS) in broccoli plots decreased 44% and 18% from the initial level of 39-40 MS g^{-1} soil in conventional and organic systems, respectively, in contrast to increasing 27% in conventional and 31% in organic lettuce plots. In both systems, wilt was less severe when rotated with broccoli than with lettuce. Strawberry canopy diameter and shoot weight were greater in broccoli plots than in lettuce plots while no significant difference in root length was observed. Cumulative strawberry yield was highest in fumigated control, followed by plots rotated with broccoli and lettuce. Rotation with broccoli could thus be used for Verticillium wilt management in both production systems.

EXECUTIVE SUMMARY

This projects was initiated to test the efficacy rotations with broccoli, and lettuce on strawberry yield, root infection, systemic vascular colonization, incidence of soilborne diseases on strawberry, and pathogen survival in the soil under conventional and organic production systems; and to calculate costs and benefits of sustainable alternatives such as broccoli rotational crop to chemical fumigants and to determine their relative profitability under conventional and organic production systems. The influence of vegetable crop rotations and residue incorporation on growth, disease severity, and yield of strawberry were compared in conventional and in organic production systems in 2000-2001 and 2001-2002. In both systems, high level of background *Verticillium dahliae* inoculum (39 to 40 microsclerotia g^{-1} soil) was present. The rotation scheme consisted of two successive crops of broccoli and lettuce followed by strawberry that was planted in November 2000 and 2001. After two crops of vegetables in 2001, the numbers of *V. dahliae* microsclerotia in broccoli plots were 44 and 18% lower than the initial numbers in conventional and organic plots, respectively. In contrast, numbers of microsclerotia in fumigated plots were >90% lower than initial numbers. In plots rotated with lettuce, however, numbers of microsclerotia increased by 27% in conventional and 31% in organic production systems. In both production systems, strawberry plants in broccoli rotation plots had significantly higher plant diameter and shoot dry weight than in lettuce plots. Verticillium wilt severity on strawberry plants in plots rotated with broccoli was nearly identical to those in fumigated plots throughout the season and was significantly lower than in plots rotated with lettuce. Strawberry yield was highest in fumigated control, intermediate in broccoli and lowest in the lettuce rotated plots. In conventional and organic production systems marketable strawberry yield in plots rotated with broccoli was 14 and 16% higher, respectively, than in lettuce-rotated plots. Data from 2001-2002 are still being collected but available data suggest similar trends during this season as well.

INTRODUCTION

Strawberry is an important horticultural crop in California, with an annual farm gate value of over \$750 million. Pre-plant soil fumigation of strawberry fields with methyl bromide+chloropicrin is the prevailing production practice to control weeds, soilborne pathogens, and nematodes. The imminent loss of methyl bromide due to environmental concerns has accelerated the search for sustainable alternatives to methyl bromide. Among the soilborne pathogens, Verticillium wilt is the most important strawberry disease causing the death of whole plants. There is no resistance against Verticillium wilt in currently grown strawberry cultivars. *Verticillium dahliae* the causal agent of wilt disease has a wide host range and is distributed in most California agricultural soils. The microsclerotia of *V. dahliae* can survive in the soil for many years. Strawberry cultivars are highly susceptible to *V. dahliae* infection with as few as 2 microsclerotia per gram of soil causing 100% disease incidence.

In some production systems crop rotation can be considered as an economically viable means of reducing the soilborne propagules of Verticillium and yield losses from wilt disease. Broccoli is the most promising rotation crop with many advantages. Broccoli is not susceptible to Verticillium wilt, is grown extensively in the coastal valleys and broccoli residue has been shown to be detrimental to *V. dahliae* propagules in soil. Previous field trial results have consistently demonstrated the effectiveness of broccoli rotation and residue amendment for Verticillium wilt management in cauliflower. After four consecutive crops of broccoli, the *V. dahliae* microsclerotia were completely eliminated in a field with a background inoculum of about 40 microsclerotia per gram of soil. In the current study, the feasibility of using broccoli rotations as an alternative to chemical fumigants in two strawberry production systems was tested. The objectives of this project were to determine the effects of rotation with broccoli and lettuce on strawberry growth, yield, disease severity and on soil populations of pathogen propagules.

MATERIALS AND METHODS

Experimental site. Experiments to evaluate the effects of crop rotation in conventional and organic strawberry production systems on soilborne diseases were established at the Monterey Bay Academy (MBA) at Watsonville, California. These locations are approximately 200 m apart and have not been planted to strawberries at least during the past 15 years. Since both locations are in proximity and their soil type is identical (Elder sandy loam), comparative studies will provide valid data on the feasibility of this approach in these production systems. At both locations, the same commercial grower is responsible for crop production. Inoculum density of *V. dahliae* was 39 microsclerotia g^{-1} soil in the conventionally managed plots and 44 microsclerotia g^{-1} soil in the organically managed plots. Both locations were naturally infested with other soilborne strawberry root pathogens (*Pythium*, binucleate *Rhizoctonia*, and *Cylindrocarpon* spp.).

Treatments and experimental design. There were two rotation treatments both in conventional and organic production systems. The crops were planted in the following sequence: lettuce-lettuce-strawberry and broccoli-broccoli-strawberry. The treatments were laid out in a randomized complete block design with four replications. In both systems, the individual plots consisted of six 52-inches-wide single beds of 25 ft. length. Standard grower production practices were followed during each crop cycle. The rotational crops were transplanted during February 2000 and 2001 and the planting cycles were timed to include two rotational crops of lettuce and broccoli each year.

At crop maturity during each season, all lettuce and broccoli marketable heads were harvested in both production systems, and the remaining residue was flail shredded, air dried on the surface for a minimum of two days and incorporated into the soil using a rototiller. Four weeks after incorporation, the beds in all plots were reworked for the next crop cycle. The rotational crops were again transplanted in May 2000 and 2001 and the harvest and residue incorporation process repeated in August. Four weeks after incorporation, the beds in all plots were reworked for the next crop cycle. Strawberries (cv. Aromas) were planted during November 2000 and 2001 in all plots (including a replicated plot fumigated with methyl bromide+chloropicrin (67+33) for comparison with rotation treatments in the conventional production system). Again standard grower production practices are being followed during the strawberry crop cycle.

Soil samples to determine the densities of *V. dahliae* propagules were collected at beginning and at the end of rotational crop, and every month during the strawberry crop. Samples were assayed using the modified Anderson sampler technique and semi-selective NP-10 medium and the colony counts were converted into microsclerotia g^{-1} soil for each treatment.

<u>Shoot and root measurement</u>: Two plants were excavated from each side of 20 plants marked for yield data in each bed on June 01, 2001 and 2002. Fresh shoot was separated by cutting the crown from main root and a total of 16 strawberry shoots per plot were weighed. Soil was collected for root extraction between the two strawberry plants with a 1.9-cm diameter soil sampler at a depth of 25 cm. Four soil cores were collected randomly from each bed with a total of 16 cores per plot and composited them. Root length was measured with flat-bed Delta-T Scanner (Austin, TX).

<u>Plant canopy, yield and disease determinations.</u> To determine the relative effects of different rotation treatments, plant growth during establishment was monitored by recording plant canopy diameter of 20 plants in each replication every month. Twenty plants per plot were visually rated for Verticillium wilt severity to monitor disease progress every other week from June. The disease severity estimate was done on the scale of 0 to 8, where 0 = healthy plant, 2 = moderately stunted, 3 = moderately stunted, slight rosette of dead leaves, 4 = moderately stunted, moderate rosette, 5 = significantly stunted, slight rosette, 6 = significantly stunted, moderate rosette, 7 = significantly stunted, significant rosette, 8 = dead plant. Marketable and non-marketable (culls) yield of strawberry were obtained in the plots once a week.

<u>Data analysis.</u> Differences between treatments for strawberry shoot and root weight, plant canopy diameter, disease severity and marketable yield were determined by analysis of variance, and means were compared by the least significant difference test ($P \leq 0.05$). Numbers of microslcerotia in each treatment were expressed as microsclerotia g^{-1} of air dry soil. Means and the corresponding standard errors were computed for each treatment and sampling time. Repeated measures analysis of variance was used to test disease severity from different treatments recorded over time. All analyses were done using SAS (release 6.12 ed., SAS

Institute, Cary, NC). Complete results are available only from the 2000-2001 cycle. Data collection and analyses, and soil processing in the 2001-2002 experiment is still in progress.

RESULTS

Baseline *V. dahliae* inoculum densities in both conventional and organic plots were high with 39 microsclerotia g^{-1} and 44 microsclerotia g^{-1}, respectively. The inoculum levels were significantly affected by the vegetable rotation practiced. The lettuce rotation treatment was more conducive for inoculum build up; microsclerotia increased 27% in conventional system and 31 % in organic system after two crops (Fig. 1). The impact of two additional crops of lettuce are still being assessed. In contrast, in broccoli rotated plots inoculum levels (after two crops of broccoli) were reduced by 44% in conventional and 18% in organic system, respectively. Very few detectable microsclerotia (2.5 microsclerotia g^{-1} soil) were present in the fumigated control plots (Fig. 1). Data available from the second year indicate that there were further significant reductions in the inoculum. The statistical significance of these data, however, is yet to be determined.

Strawberry shoot weight was highest in fumigated control, intermediate in broccoli and lowest in lettuce rotated plots in conventional system (Fig. 2). In the organic system, broccoli rotated plots had significantly greater strawberry shoot weight than in plots rotated with lettuce (Fig. 2). Root length, however, was neither influenced by the rotation treatments nor affected by the fumigation (Fig. 2). Treatment effects on all of these parameters were identical during the second year.

In both production systems, significantly large strawberry plant canopy diameter was recorded in broccoli rotation treatment. In contrast, strawberry grown in lettuce rotated plots in both systems had significantly smaller plant diameter than other treatments (Fig. 3). In the conventional production system, the greatest strawberry plant diameter was observed in the fumigated control treatment followed by broccoli rotated plots. Data from the second cropping cycle also suggest similar treatment differences.

The repeated measures analysis of variance indicated that the rotation treatments had a significant effect on the strawberry disease severity in both conventional and organic plots (Figs. 4,5, and 8). Strawberry plants grown in lettuce rotated plots had the highest disease severity rating, about 17-31% higher than in the broccoli rotated plots in organic strawberry production (Figs. 5 and 8). Similarly, in the conventional strawberry production system, disease severity was 7-34% higher in lettuce rotated plots than in broccoli rotated plots, and progressively, these differences were magnified from June to August. Plants grown in broccoli rotation treatment showed a consistently lower disease severity rating than in lettuce rotation throughout the season both in conventional and organic strawberry production systems. In conventional system, however, disease severity of broccoli was next only to that of fumigated control during the first four observation dates but there was no significant difference between broccoli and fumigated control during last two observed dates (Fig. 4). Petioles and roots from diseased plants from both convention and organic systems when plated on NP-10 medium yielded *V. dahliae*. Rotation also might change other microbial population. However, there is no significant different on the *Pythium* population in between broccoli and lettuce rotated plots in both production systems (data not shown). Data from the second cropping cycle are still being collected.

Fumigated control produced the highest cumulative marketable yields obtained in conventional strawberry production system and it was 22% higher than in broccoli (Fig. 6). However, broccoli yielded 14% higher marketable strawberry yield than in lettuce rotated plots (Fig. 6). In organic production system, cumulative strawberry yields in lettuce rotated plots were significantly lower (16% lower) than in broccoli rotated plots (Fig. 7). Yield data collection from the second cropping cycle is still ongoing.

DISCUSSION

Results obtained thus far demonstrate the significant effects of different vegetable crop rotation on strawberry plant growth, yield, Verticillium wilt severity and on *V. dahliae* propagules in soil. Among the vegetable crops tested, rotations with broccoli had the most beneficial effects on strawberry growth and yield both in conventional and organic production systems. The beneficial effects of broccoli rotation were also expressed in the reduced yield loss in the presence of *V. dahliae* and other soilborne fungal pathogens. The beneficial effects of broccoli rotation in management of soilborne fungal diseases had been previously reported for short duration crops. This is the first time that sustained beneficial effects of broccoli rotation have been reproduced in a long duration crop such as strawberry. Although no significant differences between lettuce and broccoli rotation in conventional and organic strawberry production systems were observed for *Pythium* propagules, it is unclear at this time whether pathogenic *Pythium* spp. were affected as we did not identify the pathogen to the species level.

According to the cost-benefit analysis projections (Appendix 1) for one season of broccoli/strawberry crop rotation system, the broccoli–strawberry rotation promises to be as an economically viable option under moderate level of Verticillium wilt disease pressure. The experiments are being repeated at both in conventional and organic production systems this year. At the end of this year, we will have further data to demonstrate the economic viability of broccoli – strawberry rotation to reduce soilborne diseases in strawberry.

The details of field experiments on use of vegetable rotations as non-chemical alternatives to methyl bromide fumigant and the results obtained were discussed with strawberry growers and researchers during field days, regional growers meetings and scientific meetings.

SUMMARY AND CONCLUSIONS

In the strawberry production system, feasibility of vegetable crop rotations was tested as non-chemical and environmentally safe alternative to chemical fumigant methyl bromide. In both conventional and organic strawberry systems with high Verticillium wilt disease pressure, broccoli rotations with residue incorporation resulted in better strawberry plant growth and marketable yield, lower yield loss, low disease severity and reduction in *V. dahliae* population in soil. Preliminary data suggest that this practice can also be economically viable in the post-methyl bromide era. For strawberry production in California central coast, under high inoculum levels broccoli rotation (>10 microsclerotia g^{-1} soil) can be an effective, economical, environmentally sound and compatible management practice for reducing disease severity. The widespread adaptation of this practice by conventional strawberry growers in California may not occur until fumigation with methyl bromide is no longer possible. However, rotations with broccoli would be an economically viable disease management practice for the organic strawberry growers.

Appendix 1

Comparative strawberry and broccoli production system average costs and returns (per acre). Figures based on grower interview and observations from field trials at Watsonville and Salinas, California.

1. **Strawberry with methyl bromide fumigant (1 year crop cycle)**

Total cost	$34,386
Total Yields	5,200 trays
Total value @$7.125 per tray	$37,050
Return	$2,664

2. **Broccoli (3 month crop cycle)**

Total cost	$1,900
Total Yields	850 cartons
Total value @$6.5 per carton	$5,525
Return	$3,625

3. **Strawberry without chemical fumigant (1 year crop cycle)**

Total cost	$29,585 (Full bed plastic mulch)
	$30,485 (Partial beds plastic mulch)

Deduct methyl bromide cost $3200
Add weeding cost $900 (Partial bed plastic mulch)
Deduct weeding cost $900 (Full bed plastic mulch)

Total Yield	2,600 to 3,380 trays

Yield loss due to Verticillium
wilt at MBA ranges from 50% to 35%
without chemical fumigant

Total value @$7.125 per tray)	$18,525 to $24,083
Return	Loss of $6,402 to $11,960 (partial bed mulch) Loss of $5,502 to $11,060 (full bed mulch)

4. Two Broccoli rotation crops and one Strawberry crop

Strawberry cost	$29,585 (full bed mulch)
	$30,485 (Partial bed mulch)

Deduct methyl bromide cost $3200
Deduct weeding cost $900
(data suggest that broccoli may also reduce weed populations)

Broccoli cost (Two crops)	$3,800
Total cost	$33,385 to 34,285
Strawberry Yields	3,900 trays

Average yield loss due to
Verticillium wilt 25% with
Broccoli rotation (MBA field data).

Strawberry value @$7.125 per tray	$27,787
Broccoli yields (Two crops)	1700 cartons
Broccoli value (Two crops) @$6.5 per carton	$11,050
Total value	$38,837
Return	$4,552 to $5,452

Effects of Vegetable Rotation on Inoculum Densities of *Verticillium dahliae*

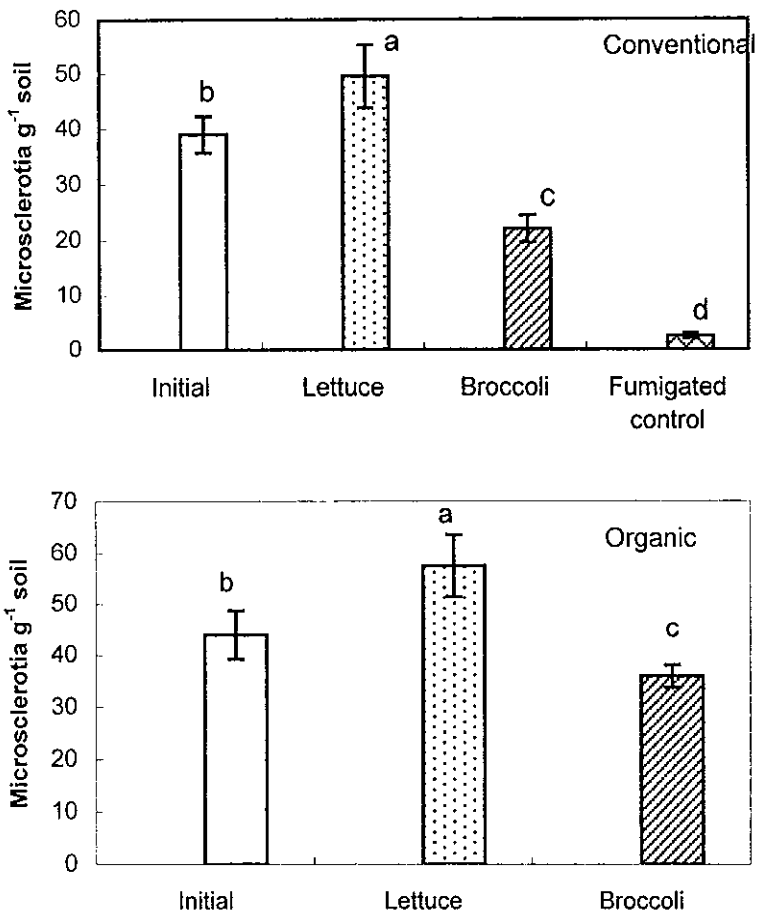

Fig. 1

Effects of Vegetable Rotation on Shoot and Root of Strawberry

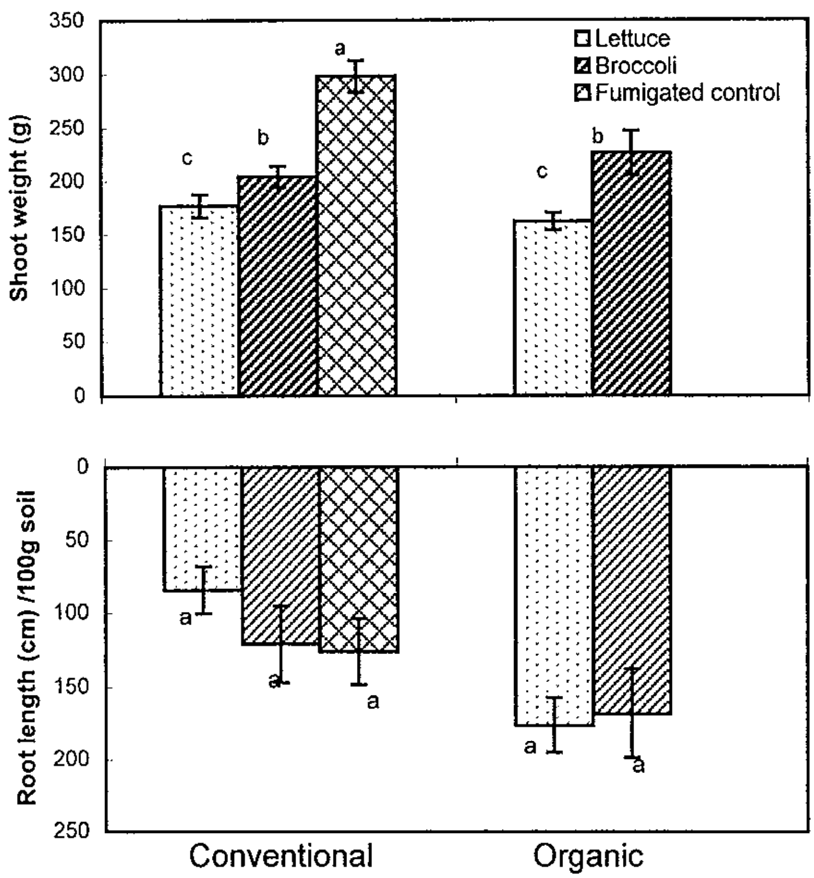

Fig. 2

Fig. 3. Effects of Vegetable Rotation on Strawberry Canopy Diameter

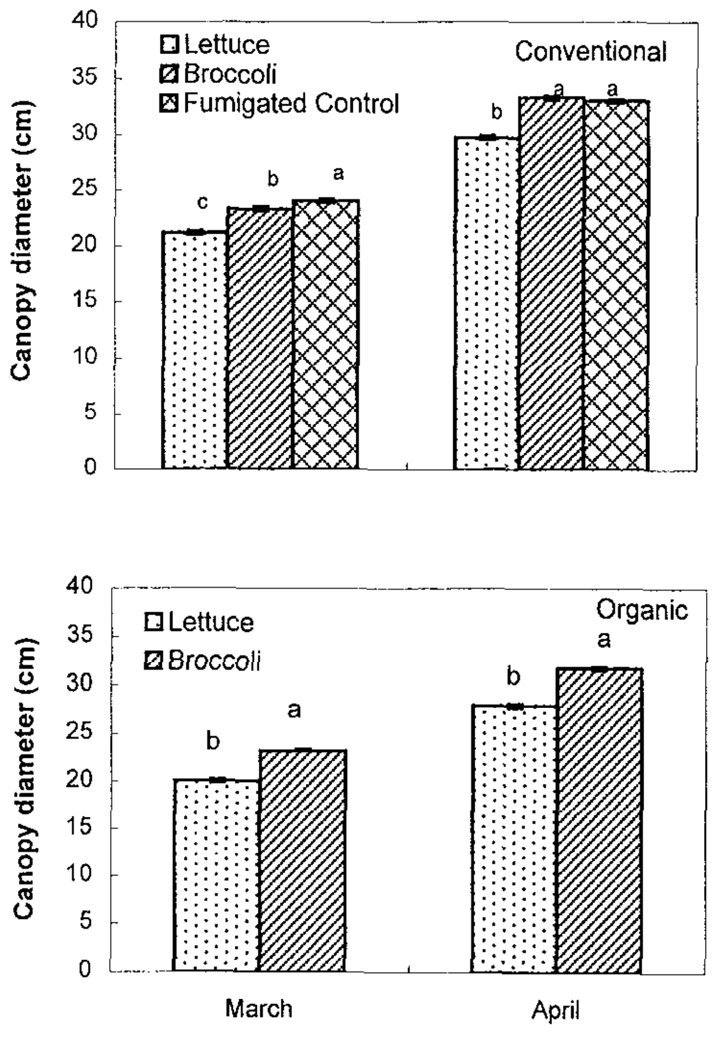

Fig. 4 **Effects of Vegetable Rotation on *Verticillium* Wilt Severity in Conventional Strawberry**

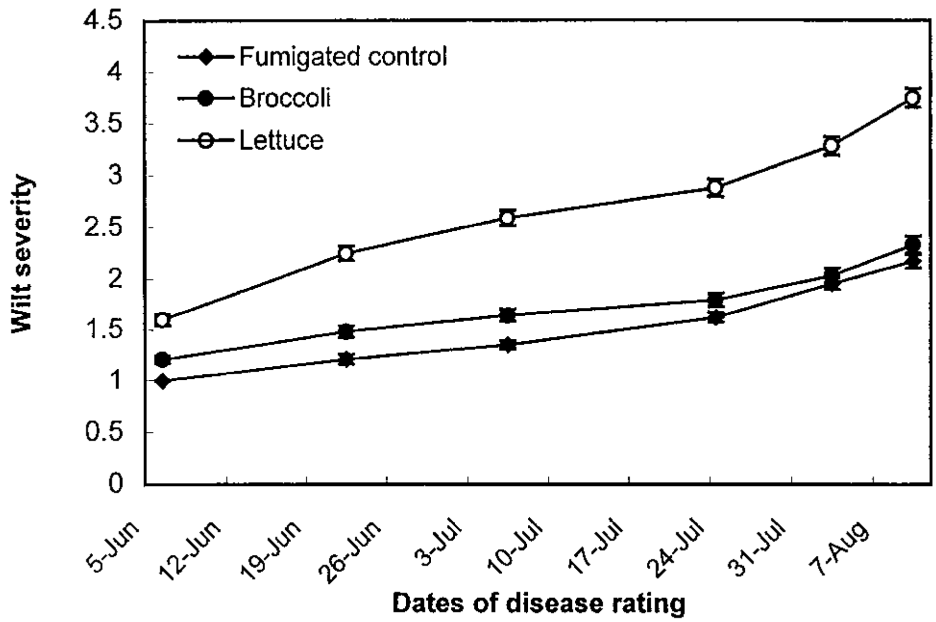

Fig. 5. Effects of Vegetable Rotation on *Verticillium* Wilt Severity in Organic Strawberry

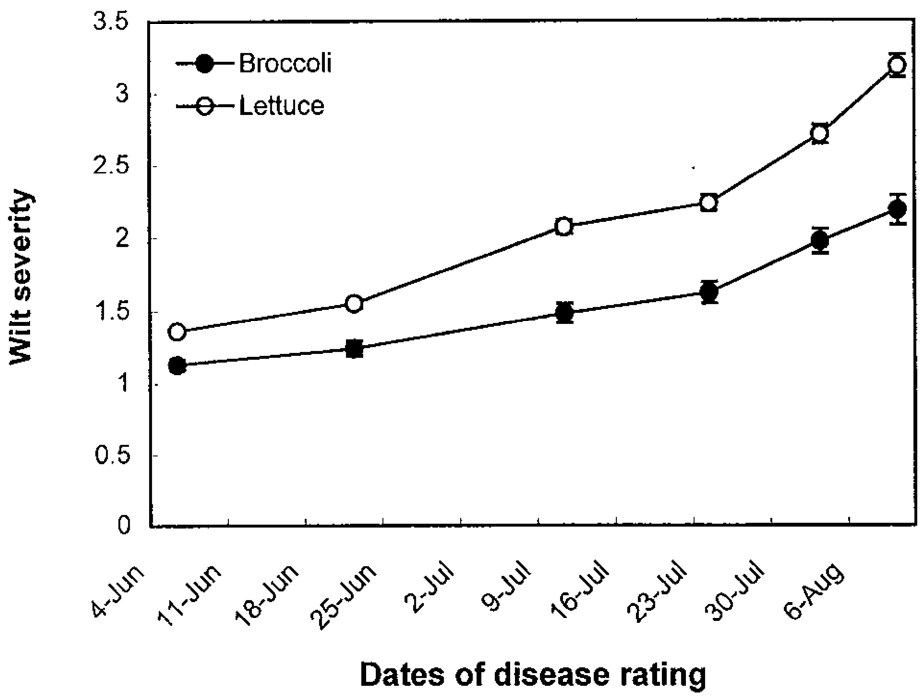

Fig. 6. Effects of Vegetable Rotation on Cumulative Marketable Conventional Strawberry Yield

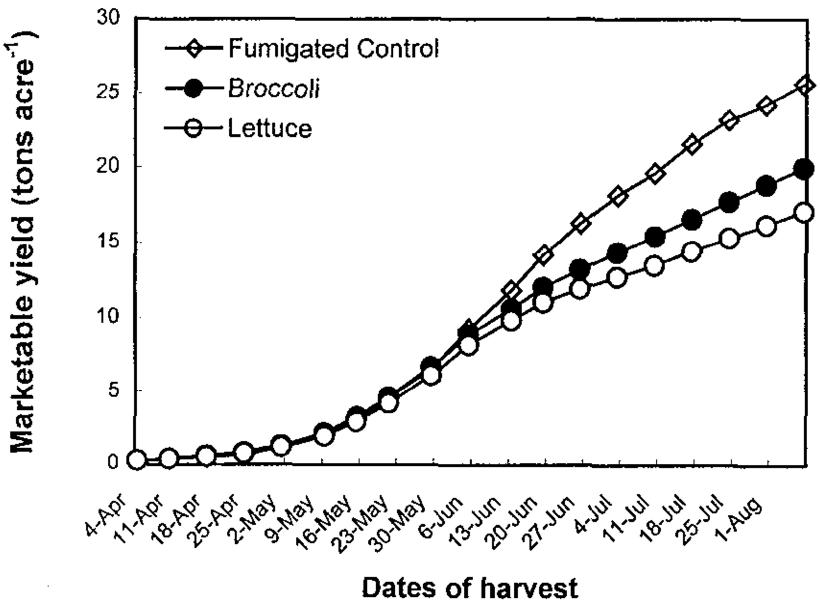

Fig. 7. Effects of Vegetable Rotation on Cumulative Marketable Organic Strawberry Yield

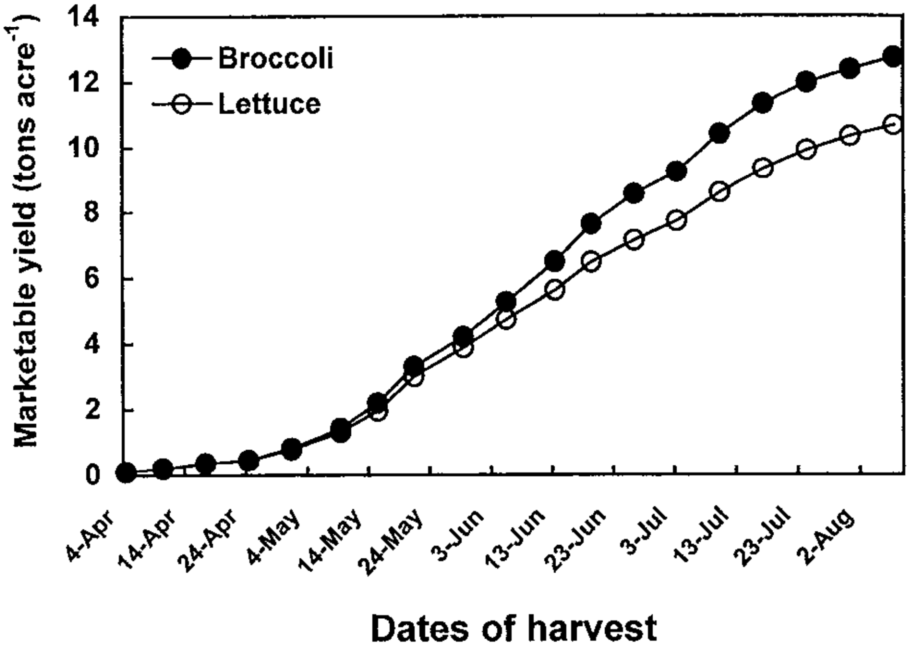

Fig. 8. Effects of Vegetable Rotation on Verticillium Disease Incidence in Strawberry Production at MBA, 2001